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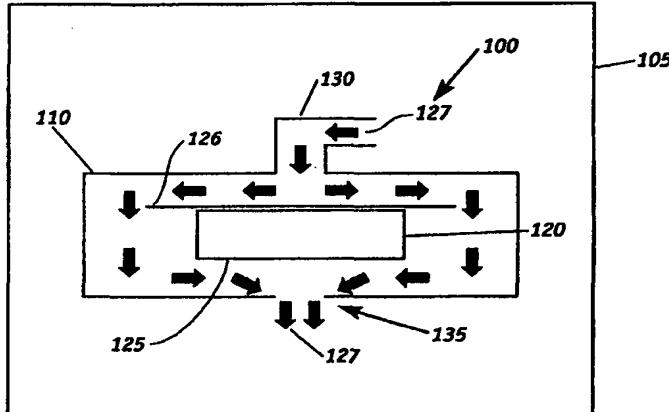
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G03F 7/20		A1	(11) International Publication Number: WO 99/57607 (43) International Publication Date: 11 November 1999 (11.11.99)
(21) International Application Number: PCT/US99/06660		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 26 March 1999 (26.03.99)		Published <i>With international search report.</i>	
(30) Priority Data: 09/071,359 30 April 1998 (30.04.98) US			
(63) Related by Continuation (CON) or Continuation-in-Part (CIP) to Earlier Application US 09/071,359 (CIP) Filed on 30 April 1998 (30.04.98)			
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(54) Title: PROTECTION OF LITHOGRAPHIC COMPONENTS FROM PARTICLE CONTAMINATION



(57) Abstract

A system (100) that employs thermophoresis to protect lithographic surfaces from particle deposition and operates in an environment where the pressure is substantially constant and can be sub-atmospheric. The system (thermophoretic pellicle) comprises an enclosure (110) that surrounds a lithographic component (120) whose surface (125) is being protected from particle deposition. The enclosure is provided with means (130) for introducing a flow of gas (126) into the chamber and at least one aperture (135) that provides for access to the lithographic surface for the entry and exit of a beam of radiation, for example, and further controls gas flow into a surrounding low pressure environment such that a higher pressure is maintained within the enclosure and over the surface being protected. The lithographic component can be heated or, alternatively the walls (110) of the enclosure can be cooled to establish a temperature gradient between the surface of the lithographic component and the walls of the enclosure, thereby enabling the thermophoretic force that resists particle deposition.

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PROTECTION OF LITHOGRAPHIC COMPONENTS
FROM PARTICLE CONTAMINATION

BACKGROUND OF THE INVENTION

This invention pertains generally to method and apparatus for preventing
5 surface contamination by deposition of particulate matter and more particularly to
preventing deposition of particulate matter onto lithographic components such as
reticles (masks) and wafers during lithographic use, fabrication, inspection, repair,
handling and storage.

The ability to produce high quality microelectronic devices and reduce
10 yield losses is strongly dependent upon maintaining the surfaces substantially
defect-free. This is particularly true as design rules drive integrated circuits to
finer feature size. Generally, surface defects can be related to particulate matter
being deposited onto surfaces of reticles (masks) and wafer substrates during the
various operations required to produce integrated circuits. The need to maintain
15 these surfaces substantially free of particulate matter has long been recognized in
the microelectronics industry and various schemes to do so have been proposed,
such as those set forth in U.S. Patent Nos. 5,373,806 and 5,472,550. The former
discloses the use of thermal energy, such as the use of radiant energy, RF, or
resistance heating, to substantially eliminate electrostatic attraction as a mechanism
20 for particle transport and deposition during gas phase processing while the latter
describes the use of the photophoretic effect to capture particles by projecting a
laser beam inside the processing chamber along a trajectory that does not contact
the substrate surface.

The concern about printable defects caused by particle deposition onto
25 surfaces is of particular importance for the next generation of lithographies,

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including proximity x-ray lithography, direct-write and projection electron-beam lithography (SCALPEL), direct-write and projection ion-beam lithography, and extreme ultraviolet (radiation having a wavelength in the region of 3.5 - 15 nm) lithography (EUVL) which must provide for exclusion of particles with diameters greater than 0.01 μm . The situation is exacerbated by the fact that for a beam of high energy radiation (photons, electrons, ions, or atoms), such as used for the aforementioned advanced lithographies, a pellicle which is customarily employed to protect lithographic reticles (masks) from particle deposition cannot be used. The protective benefit provided by a protective membrane such as a pellicle is negated by its deleterious effect on the beam of high energy incident radiation. By way of example, a half micron thick Si film will reduce the light intensity at 13 nm by 60%, which is an intolerable reduction for most lithographic applications. Coupled with this is the difficulty of forming a durable pellicle consisting of a 1/2 μm Si film. In the case of electron lithography, the pellicle will absorb some of the electron current and, by inelastic scattering, introduce undesirable chromatic aberration into the electron beam and intolerable deviations in beam angle. While it is possible to produce organic polymeric materials in the proper thickness to form pellicles, they suffer from the disadvantage that they will decompose under the influence of high energy radiation, releasing volatile degradation products which, in turn, will coat optical surfaces and reduce their efficiency. Moreover, many of the advanced lithographic concepts must operate in a vacuum to reduce degradation of high energy radiation used for finer design rules consequently, the pellicle surface will be subjected to large changes in pressure (from 760 Torr to 5×10^{-4} Torr) over a surface area that may be as large as 100 cm^2 and thus, forces larger than a thin organic membrane pellicle can withstand will be generated.

Because of the importance of protecting lithographic surfaces, such as reticles, from deposition of particulate matter for next generation lithographies alternative protection schemes such as clean encapsulation of the exposure chamber, protective gas blankets, and in-situ cleaning of mask surfaces are being

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investigated. However, each of these alternative schemes has disadvantages and none have been developed to the point of application.

What is needed is a means to protect lithographic surfaces, such as those of the reticle and wafer, from particle deposition without comprising lithographic 5 performance or contaminating lithographic optical elements. Moreover, in order to be useful in advanced lithographic applications it is necessary that the protecting means operate effectively in a sub-atmospheric pressure environment.

SUMMARY OF THE INVENTION

The present invention generally employs a physical phenomenon known as 10 thermophoresis to protect lithographic surfaces from particle deposition and is particularly designed to operate in an environment where the pressure is substantially constant and can be sub-atmospheric. Protection from particle deposition is afforded during lithographic use, fabrication, repair, handling, and storage without compromising lithographic performance or contaminating other 15 lithographic components.

Thermophoresis can be a useful tool to overcome particle deposition onto 20 surfaces because it is capable of overwhelming those mechanisms that lead to particle deposition such as: 1) electrostatic forces, 2) inertia, 3) Brownian motion, and 4) gravity. Thermophoretic forces operate to cause particles to be driven from regions of higher gas temperature to regions of lower gas temperature. However, 25 it is known that the thermophoretic effect begins to become less effective as gas pressure is lowered, generally precluding its use where the surface to be protected is held at pressures below about 5 mTorr, as can be the case in many lithographic operations and, particularly for advanced lithographic concepts where operation in a vacuum is necessary to reduce attenuation of the radiation. The present invention discloses a novel system that reduces particle deposition onto a surface by the use of thermophoresis, directed gas flow to isolate the surface from particles in the environment, orientation of the surface to eliminate gravitational

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deposition, and elimination of electric fields to protect the surface from electrostatic deposition. This invention is designed to provide particle protection in situations where the atmosphere is at substantially constant but sub-atmospheric pressure. However, because of the novel features of this invention, which have 5 been disclosed above, the present invention can also be used in those applications where the surrounding atmosphere is at atmospheric pressure or above.

Because the system of the present invention functions in a manner similar to that of a conventional pellicle and for ease of description the system disclosed herein will be referred to hereinafter as a thermophoretic pellicle. While intended 10 principally to provide protection to reticles (hereinafter the terms reticle and mask will be used interchangeably and synonymously) from particle deposition during operation of the lithographic process, it is contemplated that the thermophoretic pellicle can also provide protection for a reticle during fabrication, inspection and repair as well as storage, manual and robotic handling. Furthermore, the 15 protection provided by the thermophoretic pellicle can extend to other lithographic components such as wafers, wafer chucks, filters, lenses, mirrors and reticle stages.

The thermophoretic pellicle, which is generally deployed in a chamber operating at a sub-atmospheric pressure, comprises an enclosure that surrounds a 20 lithographic component having a surface needing protection from particle deposition, means for introducing a flow of gas into the enclosure, and at least one aperture that provides access to the surface being protected. Here, access is defined as permitting the entry and/or exit of a beam of radiation as well as the 25 exit and control of the gas flow from the interior of the thermophoretic pellicle into the environment of the chamber containing the thermophoretic pellicle as well as admitting entry of mechanical devices, such as the probe of an atomic force microscope, into the thermophoretic pellicle. The surface of the lithographic component can be heated or, alternatively, the walls of the enclosure can be cooled to establish the required temperature gradient between the warmer surface of the

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lithographic component and the cooler walls of the enclosure that provides the desired thermophoretic force.

The present invention further provides protection from particle deposition onto a surface by employing a gas flow regime that directs particles away from the 5 protected surface, substantially eliminates undesirable electrostatic deposition by the use of electrostatic shielding, and removes gravitational deposition by preferably positioning the surface being protected in a downward facing orientation.

In order to better understand and appreciate its nature and scope the present 10 invention will now be described more fully hereinafter by way of various embodiments illustrative of the invention. This invention may, however, be embodied in many different forms and should not be construed as limited only to the embodiments set forth herein but as defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Figure 1 shows an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention discloses a system, the thermophoretic pellicle, designed to operate in an environment where the pressure is substantially constant, and can be sub-atmospheric, and employs a physical phenomenon known as 20 thermophoresis to reduce the particle count on the surface of lithographic components by a factor of as much as 10^6 for particles having diameters as small as $0.01 \mu\text{m}$ by overwhelming those mechanisms that lead to particle deposition.

It is well known that surfaces can be protected from particle deposition by 25 thermophoresis. By maintaining these surfaces at temperatures higher than their surroundings, particles are caused to migrate away from the heated surfaces. There are two critical features associated with thermophoresis generally and the thermophoretic pellicle of the present invention in particular: 1) a temperature

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gradient must be developed in the gas resident between the surface of the lithographic component being protected from particle deposition and its surroundings; the surface of the lithographic component being warmer than its surroundings, and 2) the gas pressure must be sufficiently high to enable sufficient 5 collisions between gas molecules and particles to develop a thermophoretic force. Thus, while thermophoresis vanishes in a perfect vacuum, pressures above about 100 mTorr are sufficient to establish, in most gases, a well defined temperature 10 gradient and are preferred, however, useful thermophoretic protection can be established at pressures below about 100 mTorr, although with a lowered effectiveness.

As gas pressure decreases below about 100 mTorr, the continuum nature of the gas begins to break down and the gas is less able to maintain the desired temperature gradient needed to promote thermophoresis and, as a consequence, the effectiveness of thermophoretic protection is degraded. For those lithographic 15 systems that require low overall system pressures for satisfactory performance, such as EUV lithography, direct-write and projection electron beam lithography (SCALPEL), direct-write and projection ion beam lithography, and vacuum materials processing, it is necessary to provide for a region of locally high pressure in the vicinity of the lithographic component being protected in order for 20 thermophoresis to be effective, while simultaneously maintaining the general system environment at the necessary low operating pressure. In the present invention this is done by surrounding the lithographic component by an enclosure (the thermophoretic pellicle) that can be differentially pumped, thereby providing a region of locally higher pressure around the lithographic component to permit 25 thermophoretic protection of the surface. The thermophoretic pellicle further provides for a gas flow that not only sweeps particles out of the pellicle but also eliminates the flow of particles and contaminants from the chamber environment outside the thermophoretic pellicle into the enclosure holding the protected surface. Moreover, particle deposition due to electrostatic attraction is

substantially eliminated by eliminating electrical fields in the vicinity of the protected surface. Finally, particle deposition due to gravitational effects is eliminated by orienting the protected surface in a downwardly facing orientation.

Figure 1 shows a schematic representation of an embodiment of the thermophoretic pellicle 100 that comprises, in part, the present invention. Typically, thermophoretic pellicle 100 is contained within a system chamber 105 that establishes and maintains the general system operating pressure which is substantially constant but can range from atmospheric to sub-atmospheric or supra-atmospheric. In those instances where the general system operating pressure is sub-atmospheric as would be the case, for example for advanced lithography systems such as EUV lithography, direct write and projection electron beam lithography (SCALPEL), ion beam lithography, system chamber 105 is provided with pumping means to maintain a low operating pressure within the chamber. Chamber 105 can house a lithographic apparatus, or a reticle fabrication apparatus, or an inspection apparatus and establishes the operating environment in which the thermophoretic pellicle must operate. Here, the walls 110 of thermophoretic pellicle 100 enclose a reticle 120 whose surface 125 is to be protected from particle deposition, wherein surface 125 is oriented in a downwardly facing direction and is maintained at a higher temperature than walls 110. Walls 110 can be made of any material but materials having high thermal conductivity such as silicon are preferred. Metals such as aluminum or copper are particularly preferred because of their high thermal conductivity. Moreover, the use of a metal for the walls of the thermophoretic pellicle eliminates one potential source of contamination, outgassing of the organic materials from which most conventional pellicles are typically made. It is also desirable to eliminate electrical fields from the vicinity of the reticle by constructing enclosure walls 110 from materials having high electrical conductivity, such as a metal, and to equalize any voltage difference between surface 125 and the enclosure walls 110, for example, by grounding both or by simple electrical connection.

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Thermophoretic pellicle 100 is also provided with at least one gas inlet means 130, such as a valve, to permit flow of a gas into the interior of the enclosure. It will be appreciated that the gas be as free of particulate matter as possible in order to prevent extraneous particle deposition. Gas flow out of the 5 interior of thermophoretic pellicle 100 is restricted by aperture 135 so as to maintain the pressure inside thermophoretic pellicle 100 at a value sufficient to provide effective thermophoretic protection. It is preferred that the pressure within thermophoretic pellicle 100 be at least about 30 mTorr, however, useful thermophoretic protection can be achieved where the pressure in the interior of 10 thermophoretic pellicle 100 is as low as about 1 mTorr. Any gas can be used to maintain the pressure in the interior of the pellicle enclosure, however, a gas having a low molecular weight and high viscosity such as H₂, He, or Ne is preferred. For EUV applications Ar is preferred because it possesses a low cross-section for the absorption of EUV radiation, moreover, it is relatively easy to 15 differentially pump.

Pellicle 100 is further provided with at least one aperture 135 that can be of any shape and which not only provides access to surface 125 for the entry and/or exit of a beam of radiation, as well as mechanical devices, but also permits gas flow out of the thermophoretic pellicle, thereby acting as a gas conduction barrier 20 allowing differential pumping of the enclosure. The gas flowing out of thermophoretic pellicle 100 through aperture 135 also acts to exclude from the interior of the thermophoretic pellicle particles and other contamination having its origin in system chamber 105. The ability to differentially pump the 25 thermophoretic pellicle, i.e., maintain an elevated pressure in the interior of the pellicle enclosure and over surface 125, relative to the pressure within chamber 105, makes it possible to employ the thermophoretic pellicle in applications where a low background pressure must be maintained within chamber 105. The inventors have shown that in the configuration shown in Fig. 1, wherein the distance between the surface being protected and the proximate enclosure wall is

~1 cm, the temperature difference between the two is 10 K, the interior pressure is 30 mTorr, and the operating pressure in chamber 105 is < 5 mTorr, it is possible to reduce deposition of particles greater than 0.03 μ m in diameter by a factor of about 10⁶. It should be noted that the locations of the gas inlets and apertures, 5 relative to the position of reticle 120, are chosen such as to cause gas flow 127 to be substantially parallel to and away from surface 125, thereby eliminating inertial deposition of particles onto the surface 125 of reticle 120, and reducing entry of particles or other contaminants into thermophoretic pellicle 100.

Reticle 120 can be mounted on any suitable mounting means 126, such as 10 an electrostatic chuck or an x-y stage. It is preferred that reticle 120 be mounted with surface 125 facing downward to eliminate particle deposition by gravitational settling. Mounting means 126 can be used as a source of radiative, convective, or conductive heat to heat reticle 120, a radiative heat source can be used to heat the surface 125, or a source of inductive heat can be provided, all in order to establish 15 a temperature gradient between surface 125 and the walls 110 of pellicle 100. Alternatively, walls 110 can be cooled by thermoelectric means or the use of flowing cooled fluids.

The degree of thermophoretic protection afforded a surface is a function of 20 both the pressure of the gas within the thermophoretic pellicle and the temperature gradient existing between the walls and the surface being protected. The inventors have shown that the effectiveness of thermophoretic protection is determined, principally by the difference in temperature between the walls of the thermophoretic pellicle enclosure and the surface being protected and to a lesser extent by the absolute temperatures of the reticle and walls of the enclosure. It is 25 preferred that there be a temperature gradient of at least about 1 K/cm between the surface of the reticle and the enclosure walls, wherein the surface of the reticle is warmer than the enclosure walls, coupled with a gas pressure within the thermophoretic pellicle of at least about 30 mTorr.

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In the embodiment shown if Fig. 1 the thermophoretic pellicle is used to protect a reticle during the lithographic exposure operation and the pellicle is oriented such that the protected surface desirably faces in a downward direction. It will be appreciated by those skilled in the art that the thermophoretic pellicle disclosed here can also be used in many other lithographic operations, such as protection of a wafer during exposure, inspection, storage, and handling; protection of reticles during fabrication by such processes as sputtering of metallic and semiconducting layers, ion sputtering, thermal evaporation, or molecular beam epitaxy; and reticle inspection and repair. In many of these applications it is possible that the thermophoretic pellicle cannot be used in the orientation illustrated in Fig. 1, i.e., with the protected surface oriented in a downward facing direction. Providing the operating criteria set forth above are employed, the operation of the thermophoretic pellicle described herein can be independent of orientation of the protected surface, although a higher temperature gradient may be required if the protected surface faces in an upward facing orientation to compensate for increased gravitational deposition.

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What is claimed is:

1. An apparatus for protecting a surface from particle deposition, comprising:
 - a) an enclosure containing a gas and provided with at least one gas inlet means and at least one aperture;
 - b) a substrate contained within said enclosure, said substrate having a front surface and a back surface, and wherein the aperture provides access to the front surface; and
 - c) means for establishing a temperature differential between at least the front surface of said substrate and the walls of said enclosure, wherein the front surface is warmer than the enclosure walls.
- 10 2. The apparatus of claim 1, wherein the gas inlet means and aperture are located to provide a flow of gas substantially parallel to and away from the front surface of said substrate.
- 15 3. The apparatus of claim 1, wherein the temperature gradient between the front surface of the substrate and walls of said enclosure is at least 1 K/cm.
- 20 4. The apparatus of claim 1, wherein the gas has a low molecular weight and high viscosity.
5. The apparatus of claim 4, wherein the gas is H₂, He or Ne.
6. The apparatus of claim 1, wherein the gas is Ar.
7. The apparatus of claim 1, wherein said enclosure is made of a metal.
- 25 8. The apparatus of claim 7, wherein the metal is copper or aluminum.

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9. The apparatus of claim 1, further including means for eliminating any electric field between the front surface of said substrate and said enclosure.

10. The apparatus of claim 1, wherein the front surface of said substrate is
5 oriented in a downward facing orientation.

11. An apparatus for protecting a surface from particle deposition in an environment at sub-atmospheric pressure, comprising:

10 a) an enclosure containing a gas and provided with at least one gas inlet means and at least one aperture that controls the rate of outflow of the gas to maintain a fixed pressure within said enclosure;

b) a substrate contained within said enclosure, said substrate having a front surface and a back surface, and wherein the aperture provides access to the front surface; and

15 c) means for establishing a temperature differential between at least the front surface of said substrate and the walls of said enclosure, wherein the front surface is warmer than the enclosure walls.

12. The apparatus of claim 11, wherein the gas inlet means and aperture are located to provide a flow of gas substantially parallel to and away from the
20 front surface of said substrate.

13. The apparatus of claim 11, wherein the temperature gradient between the front surface of said substrate and walls of said enclosure is at least 1 K/cm.

14. The apparatus of claim 11, wherein the fixed pressure within said enclosure is above about 1 mTorr.

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15. The apparatus of claim 11, wherein the front surface of said substrate is oriented in a downward facing orientation.
16. The apparatus of claim 11, wherein the gas has a low molecular weight and high viscosity.
- 5 17. The apparatus of claim 16, wherein the gas is H₂, He, or Ne.
18. The apparatus of claim 11, wherein the gas is Ar.
19. The apparatus of claim 11, wherein said enclosure is made of a metal.
20. The apparatus of claim 19, wherein the metal is copper or aluminum.
21. The apparatus of claim 11, further including means for eliminating any electric field between the front surface of said substrate and said enclosure.
- 10 22. An apparatus for protecting a surface of a reticle from particle contamination in a low pressure environment, comprising:
 - a) an enclosure containing a gas and provided with at least one gas inlet means and at least one aperture that controls the rate of outflow of a gas to maintain a fixed pressure within said enclosure;
 - 15 b) a reticle contained within said enclosure, said reticle having a front and a back surface, wherein the front surface of said reticle is oriented in a downward facing orientation, and wherein the aperture provides access to the front surface of the reticle;
 - 20 c) means for eliminating any electric field between the front surface of said reticle and the walls of said enclosure; and

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d) means for establishing a temperature differential between at least the front surface of the reticle and the walls of said enclosure, wherein the front surface is warmer than the enclosure walls.

23. A method for protecting a surface from particle contamination in a low 5 pressure environment, comprising:

a) providing an enclosure having at least one gas inlet means and at least one aperture that controls the rate of outflow of a gas to maintain a fixed gas pressure within the enclosure;

10 b) placing a substrate having a front and a back surface within the enclosure, wherein the flow of gas is substantially parallel to and away from the front surface of said substrate, and wherein the aperture provides access to the front surface;

15 c) establishing a temperature differential between the front surface of the substrate and the walls of the enclosure, wherein the front surface of the substrate is at a temperature higher than the temperature of the walls of the enclosure; and

d) eliminating the electric field between the front surface of the reticle and the walls of the enclosure.

24. The method of claim 23, further including orienting the front surface of the substrate in a downward facing orientation.

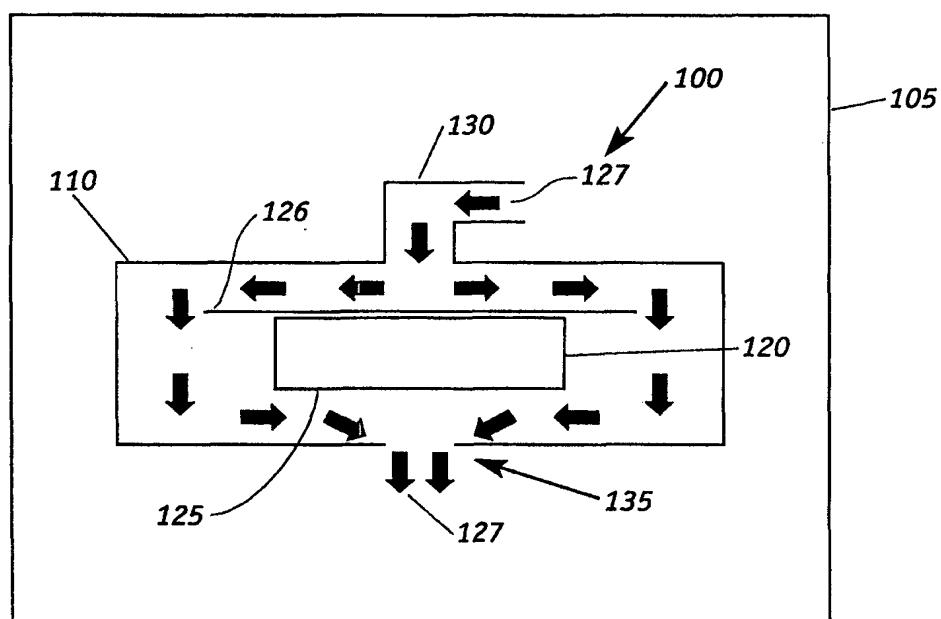
20 25. The method of claim 23, wherein said step of establishing includes heating the front surface of the substrate to a temperature higher than the walls of the enclosure.

26. The method of claim 23, wherein said step of establishing includes heating the back surface of the substrate.

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27. The method of claim 23, wherein said step of establishing includes cooling the walls of the enclosure to a temperature below the temperature of the front surface of the substrate.

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**FIG. 1**

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/06660

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G03F7/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 408 350 A (CANON KK) 16 January 1991 (1991-01-16) page 3, line 14 – page 5, line 45 figures 1-3	1,4,5,7, 11,14, 16,17,19
A	---	22,23
X	EP 0 676 672 A (CANON KK) 11 October 1995 (1995-10-11) column 2, line 34 – column 4, line 58 figure 1	1,4,5,7, 11,14, 16,17,19
A	---	22,23
		-/-

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Date of the actual completion of the international search

15 July 1999

Date of mailing of the international search report

22/07/1999

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/06660

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 581 324 A (MIYAI TSUNEO ET AL) 3 December 1996 (1996-12-03) column 34, line 58 - column 36, line 64 figures 19-21 -----	1,10
A	-----	11,22,23
X	US 5 550 633 A (KAMIYA SABURO) 27 August 1996 (1996-08-27) column 4, line 15 - column 7, line 16 figures 1,2 -----	1,2
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Information on patent family members

Int'l Application No

PCT/US 99/06660

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